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***Abstract*— In this paper, multiple-input multiple-output (MIMO) millimeter-wave wide scan beam 5G antenna array for 28 GHz application in the mobile terminals is presented. The MIMO antennas operate in 25-30 GHz in the end-fire direction. The antenna array composed of eight-element tapered tilted dipole antennas. The proposed antenna array can scan the beam in a wide coverage region from ± 80 degrees in wide operating bandwidth with scan loss better than 3 dB. The antenna coverage efficiency is better than 94 %, 78%, and 52 % for minimum realized gain of 0, 5, and 8 dBi respectively. The antenna has a good impedance matching (S11< -10 dB) and mutual coupling better than -28 dB in whole operating frequency bands from 25-30 GHz.**

***Index Terms*—Antenna, 5G, millimeter-wave, 28 GHz, mobile terminal, multiple-input multiple-output (MIMO), phased array antenna.**

I. Introduction

The demand for high data rate communication motivated the researchers to design antenna and system in 5G millimeter-wave (mm-wave) frequency range. Due to challenges in mm-wave applications such as strong attenuation and fading, it is desirable to design a steerable high gain antenna that overcomes the limitation of path loss and absorption loss, shadowing and user effect [1-2]. Different frequency spectrum has been proposed for 5G scenario. The 28 GHz frequency, due to the lowest attenuation absorption, is one of the best candidates to be used in 5G application [3].

In the literature, several papers report mm-wave 5G antenna design and methodology in mobile terminal [4-8]. A broadband mm-wave dipole array antenna is presented in [4]. The maximum scan range of this antenna is 60 degrees. An overview and experimental demonstration for millimeter-wave 5G antennas in smartphones is presented in [5]. By the use of slot in a different position, 3D beam coverage can be attained with the help of exciting surface waves in the mobile terminal in 28 GHz [6]. Statistical modeling of user effect on mobile terminal at 28 GHz is investigated in talk mode and data mode [2]. An integrated low-frequency (4G) and high-frequency 5G antenna array is presented in [7].

A compact beam-steerable end-fire antenna array is proposed for 28 GHz mobile terminals [8]. In [8], An array consists of one active element and two passive parasitic

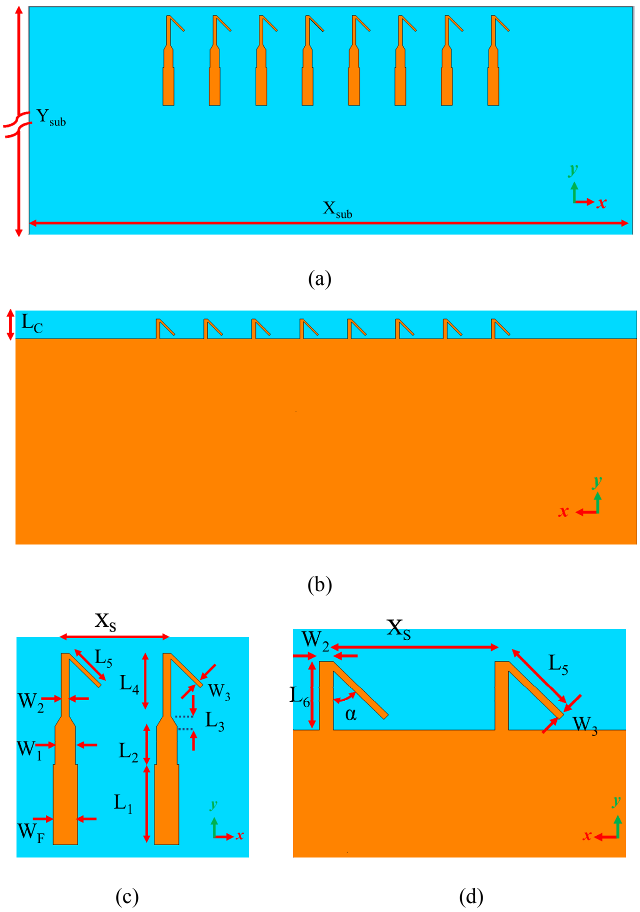


Fig. 1. The configuration of the proposed mm-wave 5G antenna array. (a) top view, (b) bottom view, (c) top view with more details and enlargement, and (d) bottom view with more details and enlargement.

elements are utilized to design the switchable beam antenna in 5G.

An important parameter of coverage efficiency, that relates to the antenna efficiency, gain, beam scanning and coverage area of antenna in mobile terminal, is introduced by [9]. The coverage efficiency is important factor for mm-wave 5G mobile terminal antenna and defined by:

$$\eta_c = \frac{Coverage\,Solid\,Angle}{Maximum\,Solid\,Angle} \tag{1}$$

The end-fire radiation pattern antenna reduces the shadowing area in data mode in the mobile terminals [2] and [7]. Consequently, the end-fire radiation pattern in data mode has coverage efficiency better than a broadside radiation pattern in the mobile terminal. So it is desirable to design end-fire radiation pattern antenna in mobile terminal instead of broadside radiation pattern antenna.

In this paper, a mm-wave 5G wide scan beam steerable end-fire MIMO antenna array for 28 GHz in the mobile terminal is presented. The proposed antenna has a wide scan region of ± 80 degrees in the wide operating bandwidth 25-30 GHz with mutual coupling better than -28 dB.

II. ANTENNA DESIGN

The configuration of proposed mm-wave MIMO 5G end-fire antenna array is shown in Fig. 1. The antenna composed of 8 element tapered tilted dipole. The antenna is designed on low loss high-frequency Nelco N9000 substrate with εr = 2.2, loss tangent of 0.0009 and thickness of 0.508 mm. The total dimension of the antenna is 65×120×0.508 mm3 which is standard dimension for mobile handset. The antenna dimensions after optimization are represented in table 1:

Table 1. The antenna dimensions and parameters.

parameter	Value (mm)	parameter	Value (mm)	parameter	Value (mm)
L_1	4	L_2	2	L_3	0.5
L_4	3.15	L_5	2.25	L_6	2
L_C	4	W_F	1.2	W_1	1
W_2	0.4	W_3	0.2	X_s	5
X_{sub}	65	Y_{sub}	120	H_{sub}	0.508

H_{sub} is the thickness of the substrate. It should be mentioned that the angle of tilted dipole (α) plays an important role in antenna matching, reduce the mutual coupling between the antenna, and wide scan functionality of the proposed antenna. After optimization, the α is set 45 degrees. On the other hand, the impedance matching transformer in the feeding line, as shown in Figure 1. (c), causes wideband impedance matching from 25-30 GHz.

The simulated reflection coefficient of the proposed mm-wave 5G beam steerable array antenna is presented in Fig. 2. It is seen that the antenna elements have good impedance bandwidth around 28 GHz from 25-30 GHz with reflection coefficient better than -10 dB. The simulated mutual coupling between the antenna element of the proposed mm-wave 5G MIMO antenna is shown in Fig. 3. It is seen that the mutual coupling is better than -28 dB in the whole operating frequency band. The envelope correlation coefficient (ECC) is an important factor in MIMO antenna which can be derived from scattering parameters of the MIMO antenna

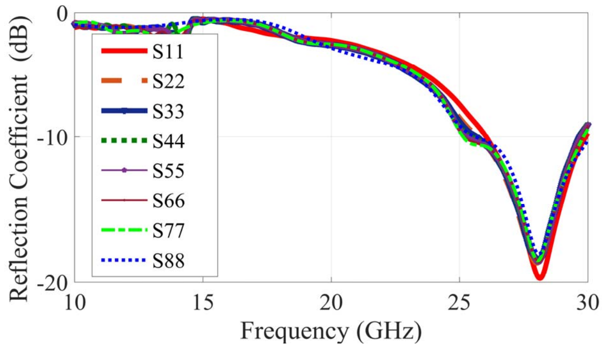


Fig. 2. The simulated reflection coefficient of the proposed MIMO mm-wave 5G end-fire beam steerable array antenna.

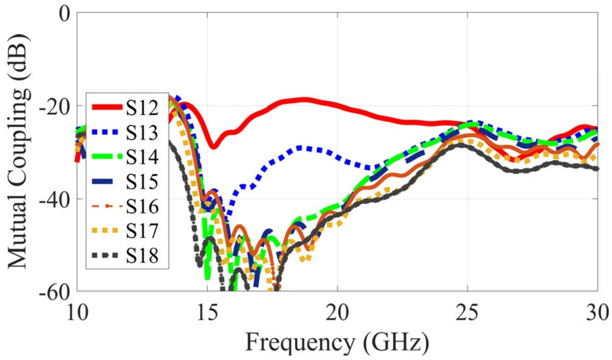


Fig. 3. The simulated mutual coupling between the antenna element of the proposed MIMO mm-wave 5G beam steerable array antenna.

array. The ECC of the propped antenna array is derived from the (2) [10]:

$$\rho_e = \frac{\left|S_{ii}^* S_{ij} + S_{ji}^* S_{jj}\right|^2}{\left|\left(1-\left|S_{ii}\right|^2-\left|S_{ji}\right|^2\right)\left(1-\left|S_{jj}\right|^2-\left|S_{ij}\right|^2\right)\right|} \quad (2)$$

The ECC of the proposed antenna is better than 0.02 in the whole operating frequency band, which is much better than the accepted value of 0.3.

The simulated realized gain of the proposed antenna array at different frequencies is presented in Fig. 4. It is seen the antenna gain varies from 10.8-13.4 dBi in 25-30 GHz. The combination of the radiation pattern of the proposed mm-wave 5G beam steerable MIMO antenna array with different input phasing at 26 GHz, 28 GHz, and 30 GHz is illustrated in Fig. 5. As shown in Fig. 5, the beam steerable radiation pattern of the proposed mm-wave antenna array results in different scan angle at 26 GHz, 28 GHz, and 30 GHz. It is seen that the proposed antenna can scan the space with a wide scan angle of ± 80 degrees in wide operating bandwidth from 25-30 GHz with scan loss better than 3 dB.

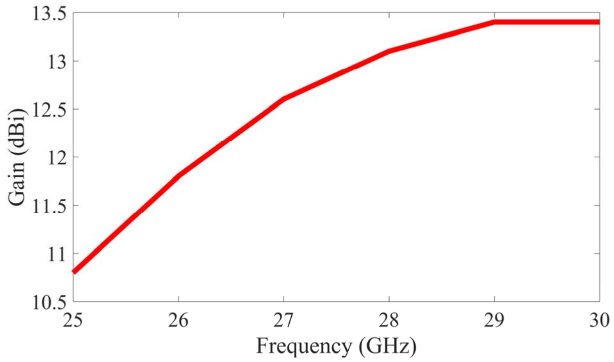
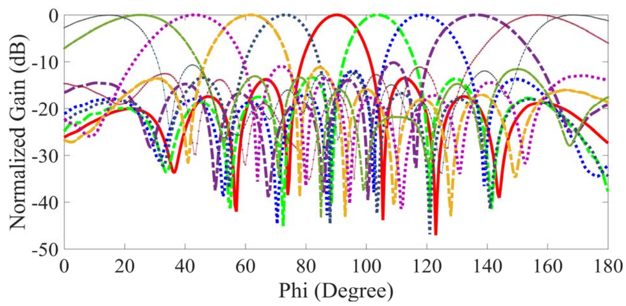
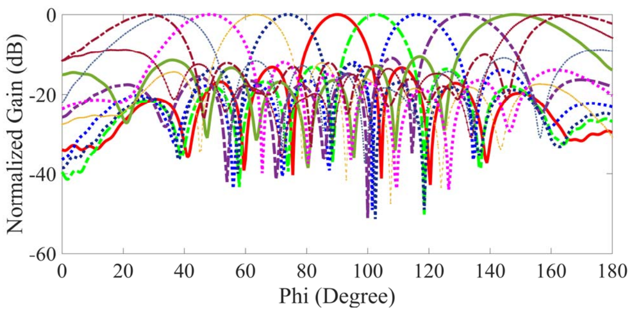


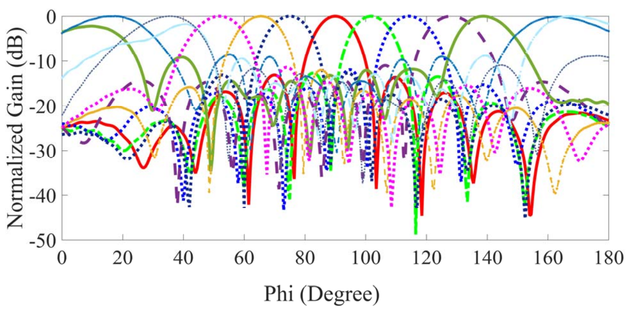
Fig. 4. The simulated realized gain of proposed antenna array at different frequencies.



(a)



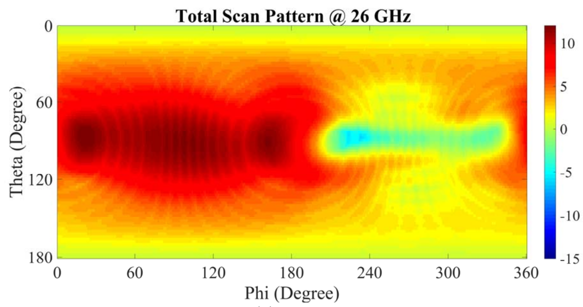
(b)



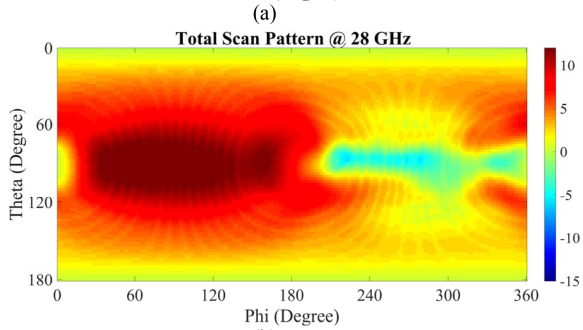
(c)

Fig. 5. The beam steerable radiation pattern of the proposed mm-wave 5G end-fire antenna array with different input phasing in which results in different scan angle at (a) 26 GHz, (b) 28 GHz, (c) 30 GHz.

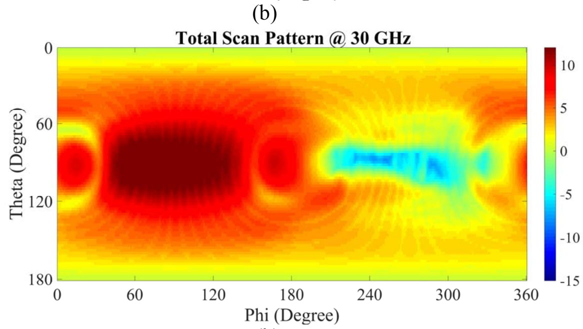
The total scan patterns of the eight-element beam steerable MIMO antenna array at different direction at frequencies of 26, 28, and 30 GHz are shown in Fig. 6. It is seen from Fig. 6, the proposed antenna array has such capability to scan wide region in sphere with high gain which is essential for 5G application. This means that the proposed antenna can cover 94 % of the sphere with a minimum gain of 0 dBi. The coverage efficiency radiation pattern concept of the proposed mm-wave end-fire beam steerable array antenna, which is introduced by (1), at frequencies of 26, 28, and 30 GHz is shown in Fig. 7. It is seen that the proposed antenna has a good coverage region with acceptable gain. The antenna coverage efficiency is better than 94 %, 78%, and 52 % for minimum realized gain of 0 dBi, 5 dBi, and 8 dBi, respectively. That means the proposed antenna array has such capability that cover 78% of the sphere with minimum gain of 5 dBi. Due to the 5G requirement, the proposed antenna is a good choice to be used in the 5G mobile terminal communication system.



(a)



(b)



(b)

Fig. 6. The total scan pattern of antenna at different direction angle at (a) 26 GHz, (b) 28 GHz, (c) 30 GHz.

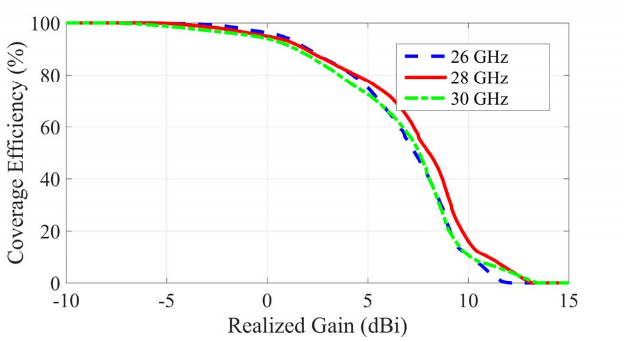


Fig. 7. The coverage efficiency radiation pattern concept of proposed mm-wave beam steerable antenna array at frequencies of 26, 28, and 30 GHz.

III. CONCLUSION

MIMO millimeter-wave wide scan beam steerable end-fire antenna array for 28 GHz 5G application in mobile terminals is presented in this paper. The antenna has a good impedance matching (S11-S88 < -10 dB) and very low mutual coupling better than -28 dB in the operating band 25-30 GHz. The antenna has a very good coverage efficiency better than 94 %, 78%, and 52 % for minimum realized gain of 0, 5, and 8 dBi respectively. The realized gain of antenna varies from 10.8-13.4 in operating bandwidth. The envelope correlation coefficient of the proposed MIMO antenna is less than 0.02. So the designed antenna is a good choice for using in the 5G mobile terminal communication system.

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